

## Variable Frequency Drives 3-Phase Motor Control

Today's microprocessor-based, PWM-output, variable frequency drives provide the user with a tremendous variety of features and functions which allow accurate control and monitoring in nearly every 3-phase motor application.

A fundamental advantage of an ac drive is that it provides virtually infinite speed control of the standard induction motors. There are many methods by which speed control is accomplished, all of which fall into one of three main categories:

- OPEN LOOP, which uses no feedback;
- SLIP COMPENSATION, which utilizes output current transducers for current feedback to estimate motor slip;
- CLOSED LOOP, in which a feedback device is mounted on the connected motor to provide a feedback signal representing actual shaft RPM.

### Open Loop

This method simply requires the ac drive to output voltage and frequency to the motor. If the drive output voltage and frequency are held constant when motor load is increased, shaft RPM will decrease due to additional required torque, which results in a greater amount of "slip." Slip is simply the difference between the applied and actual rotor frequency or RPM.

A look at the speed/torque curve (Figure 1) shows how the operating point of the motor moves up the graph to a point at which it develops the required torque. (For instance, from Point 2 to Point 3.) With open-loop control, the actual RPM decrease is not monitored and no compensation takes place. Speed regulation is therefore determined by the slip characteristics of the connected motor.

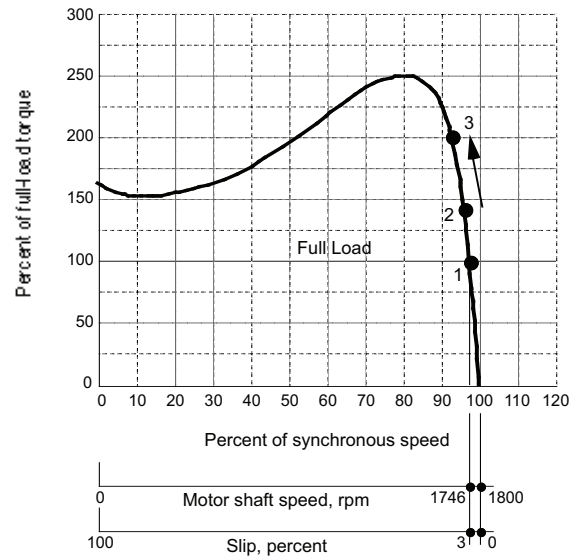


Figure 1. Typical NEMA B Speed/Torque Curve

For a typical NEMA B design motor, 100% torque is developed at Point 1, or 3% slip. This amount of speed regulation is used in hundreds of different applications with excellent results.

$$\text{Eq. (1): } N_s = \frac{120F}{P}$$

$$\text{Eq. (2): } N_{\text{actual}} = \frac{120F}{P} - \text{slip}$$

Equation (1) gives the synchronous or "no slip" speed of a motor. Using a 4-pole NEMA B design induction motor driven by a 60 Hz source, we see that the synchronous speed of the motor shaft is 1800 RPM. But, a 4-pole NEMA B design motor has a "nameplate" RPM value of approximately 1746 RPM. This number includes the slip characteristics of the motor running at nameplate conditions when a load requiring 100% torque is connected. Equation (2) is the complete equation giving the actual speed of the motor shaft.



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When an open-loop application requires regulation tighter than 3.0% , a synchronous motor can be used. If this type of motor is operated within its speed and torque parameters, the shaft RPM will follow Eq(1) and directly follow the applied frequency without a feedback device. The design of the synchronous motor is such that it eliminates the slip characteristics of the NEMA B design motor. Hence, synchronous speed control is maintained throughout the operating range. It must be noted that synchronous motors cost more than induction type and are only required in special applications.

## Slip Compensation

Slip compensation is actually a sophisticated version of the open loop concept. The slip compensation method of speed control does not monitor the actual shaft RPM. Rather, it utilizes drive output current transducers to monitor the current drawn by the connected motor. As discussed earlier, when a load is placed on a NEMA B design motor during a situation where the output frequency is held constant, the slip increases, the shaft RPM slows and the motor current increases. The difference here is that the "slip" function "compensates" for the reduction in shaft RPM by increasing the voltage and frequency applied to the motor. Figure 2 illustrates an application that requires the motor to supply full torque at 1500 RPM.

The top portion shows what occurs without slip compensation. The applied frequency is 50Hz, but the motor actual shaft RPM, due to slip, has a value of 1455. The bottom portion shows how slip compensation automatically "compensates" this situation by applying 1.5Hz additional output frequency to the existing output frequency of 50Hz, resulting in a new output frequency of 51.5Hz. The motor shaft still "slips" back, but now the actual shaft speed is the desired 1500 RPM.

The amount of slip does not actually decrease. It is simply shifted so that the actual RPM now is the desired RPM. Remember that the drive monitors current drawn by the motor, not the actual shaft RPM.

The drive must provide the user the ability to program the amount of compensation allowed so that different motor types can be used. When the function is correctly tuned to the application, speed regulation tighter than 1.0% of base speed is achievable.

There are some application situations which cannot use slip compensation. Multi-motor applications cannot use this function because the algorithm cannot differentiate which motor may be drawing more current than the others. The function will apply the same voltage and frequency to all connected motors, which would not provide desirable results. Synchronous motors cannot utilize this function due to their 0% slip design.

## Closed Loop

Closed loop speed control is required when speed regulation tighter than 0.5% of base speed is necessary.

Typical closed loop speed control requires a speed feedback device mounted to the shaft of the connected motor. The drive, of course, must have the ability to accept the signal produced by this feedback device. The drive logic compares the reference, or setpoint frequency, to the feedback frequency. The feedback value is subtracted from the reference value and a error signal is produced. It is this error signal, acted upon by the control logic, which is used to calculate a new output frequency that is applied to the motor.

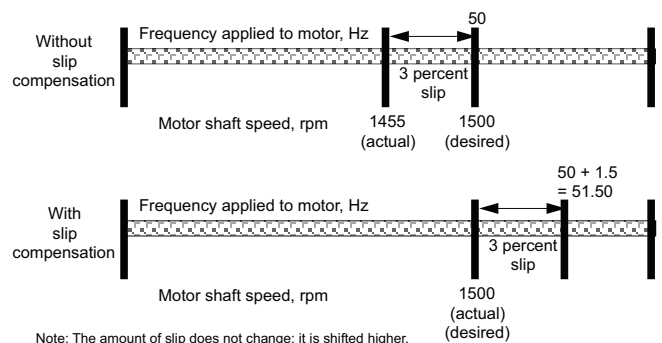


Figure 2. Slip Compensation



# Variable Frequency Drives 3-Phase Motor Control

Three types of feedback devices are commonly used in closed loop control schemes: Analog Tachometer; Resolver; and Encoder (sometimes called a Digital Tachometer or Pulse Generator).

An analog tachometer outputs a voltage proportional to the speed of the motor. Depending upon the design of the device, an ac or dc voltage is applied with the corresponding voltage brought back to the control logic, converted to a digital value and used as the speed feedback.

A resolver produces an induced analog output when a power source is applied. The resolver's output signal is compared to the applied signal and a phase shift between the two is developed. The amount of this phase shift produces feedback which is converted by the drive logic to a digital signal and applied to the motor in the manner described earlier.

The third device is an encoder, sometimes called a digital tachometer or a pulse generator. This device produces a pulse train with a frequency proportional to shaft RPM. The maximum frequency of this pulse train is called the bandwidth. This value must not be greater than the bandwidth of the feedback circuit used by the drive control logic. Encoders are available with different Pulse Per Revolution (PPR) ratings which impact the maximum allowable motor RPM and speed regulation.

To illustrate the differences between different PPR ratings, let's look at an encoder with a PPR of 1024 and one with a PPR of 2500.

we can use Equation (3) to find the bandwidth when PPR and maximum motor RPM are given.

$$\text{Eq. (3): Bandwidth} = \frac{\text{PPR} \times \text{Max motor RPM}}{60}$$

$$= \frac{1024 \times 1800}{60} = 30,720 \text{ Hz}$$

$$= \frac{2500 \times 1800}{60} = 75,000 \text{ Hz}$$

It is easy to see that the bandwidth of the feedback circuit must increase or the maximum motor RPM must decrease when a higher PPR encoder is used.

**Why use an encoder with a higher PPR?** The answer lies in the fact that pulses are physically closer together in the 2500 PPR encoder, which results in  $360^\circ/2500 = 0.144^\circ$  separation between pulses as opposed to  $360^\circ/1024 = 0.352^\circ$ . The 2500 PPR encoder will therefore tighter speed regulation, due to the fact that each pulse has a maximum error of  $0.144^\circ$  as opposed to an error of  $0.352^\circ$ .

Applications which require tighter speed control are becoming more prevalent in industry. Increased production speeds, quality control demands and sophisticated electronics at the plant floor level are demanding that ac drive controllers have the ability to accept speed feedback signals. A working understanding of these devices will enhance your ability to select, specify and operate these drive systems.

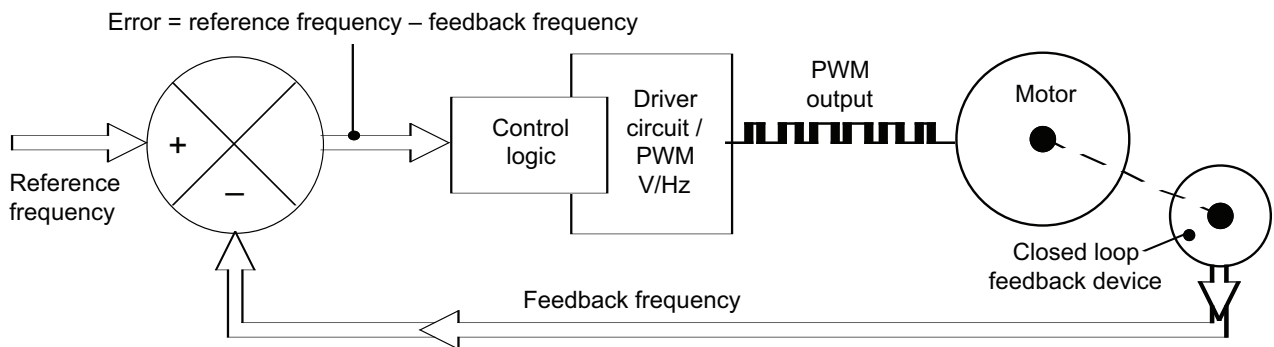


Figure 3. Simplified Closed Loop Speed Control Diagram